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Establishment of an equity evaluation method for urban parkland layout under the process-outcome perspective

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Urban parkland, as a critical component of urban green space, reflects the distribution of public resources. Combined with the concept of the 15-min Living Circle, this paper comprehensively evaluated the equity of urban parkland in the Central Area of Zhengzhou from a process-outcome perspective and established an evaluation method for assessing the equity of parkland in high-density urban areas. The objective of this approach is to provide a systematic and applicable evaluation method for metropolises that is more comprehensive than traditional evaluation methods, which rely solely on accessibility. In terms of process equity, spatial equity values were calculated using the Three Step Catchment Area Method (3SFCA) with walking and bicycle travel models. For outcome equity, Zone Entropy was utilized with demographic characteristics. The results illustrated that the overall accessibility and equity of urban parkland layout in the Central Area of Zhengzhou were inferior, with an extensive number of blind service areas and serious polarization. The Zone Entropy varied considerably among streets, which indicated significant differences in the allocation of parkland and population. Further analysis illustrated that economic factors, such as house prices, were not significantly relevant to parkland equity. Instead, geographic factors such as location and intensity of development had a remarkable impact on parkland equity. Although urban parkland layout has been prone to the elderly, the total number of park spaces is still insufficient. In the long run, the construction of the 15-min Living Circle still needs to be vigorously promoted in the research area.

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Introduction

Research background. With social and economic progress, citizens are increasingly demanding justice, equity, democracy, and the rule of law (Dai et al., 2021). In the broad sense, equity means equal distribution of resources and benefits (Dai et al., 2021; Tang and Gu, 2015; Zhang et al., 2021). As well as being a basic carrier of the ecological environment, urban parkland spaces are daily places for public recreation, fitness, and social interaction (Tang and Gu, 2015; Zhang et al., 2021). In the current urbanization process, urban land and population are rapidly growing. However, these dynamic changes can result in spatial mismatches, which may cause an uneven distribution of urban parkland and an imbalance between supply and demand (Sun et al., 2020; Huang et al., 2023; Gao et al., 2017).

In 2018, Chinese authorities introduced the document, which began to set requirements for the construction of public service facilities within a 5, 10 and 15 min Living Circle for residents¹. The Living Circle emphasizes the supply of public services within walking distance, reflecting an important initiative to promote the equalization of public facilities (Wei et al., 2019; Chen et al., 2019). In the context of Community Living Circle construction, studying the equity of urban parkland from a process-outcome perspective is conducive to promoting sustainable urban development.

In China, rapid urbanization signifies swift urban expansion and an increase in population density. Urban land utilization is constantly rising, with a substantial portion of green spaces being repurposed for infrastructure development, inevitably leading to a reduction in urban green spaces. Due to the continual outward spread of urban construction and development from city centers to the peripheries, the focus of urban development is gradually shifting from old to new urban areas. This shift is widening the developmental disparities between these areas, with new urban districts increasingly surpassing the older ones in terms of infrastructure and resource allocation. This trend has started to create an imbalance in the supply and demand of parks.

Urban parks and green spaces, as vital resources in urban construction, should be accessible to all residents. Therefore, the basic needs of urban residents for parks should include ample activity space and easy accessibility, followed by the quality and service levels of the parks. Since 2006, Zhengzhou has been honored with multiple accolades such as “National Forest City,”² “National Ecological Demonstration City,” and “National Garden City,” indicating significant achievements in ecological and environmental construction. However, there is currently a lack of a systematic evaluation method for the layout of urban parkland in Zhengzhou. Characterized by high density, the Central Area of Zhengzhou is densely populated, showing a gradual dispersal layout from the inside out. This leads to an imbalance in the distribution and capacity of parkland between new and old urban areas. As a result, analyzing the spatial layout of urban parks can help mitigate this issue and achieve social equity.

Research terms. Justice and equity encompass a wide range of dimensions. To assist the reader in understanding the content of this study, the following terms were defined.

JUSTICE focuses on administering justice and refers to the act of bringing fairness to two or more parties to a dispute. As a sociological term, EQUITY is one of the fundamental values sought by law. A public entity means that everyone is public, and equity means that everyone has equal rights (Tang and Gu, 2015). Taken together, JUSTICE focuses on behavior and EQUITY focuses on groups. Therefore, this study focused on equity.

In this context, DEMOCRACY refers specifically to the right of citizens to participate in the management of social affairs or to

express their views freely on those. THE RULE OF LAW refers to the mechanism of social management, the mode of social activity, and the state of social order, with democracy as the prerequisite and foundation. VULNERABLE GROUP refers to a social group that has more difficulties in distributing and acquiring social wealth due to the group’s relatively weak strength in the productive life of society. Vulnerable groups in this study include children under 14 years and elderly people over 65 years. The definition of 15-MINUTE LIVING CIRCLE is proposed in the Planning and Design Standards for Urban Residential Areas introduced in 2018. The 15-min living circle is a service radius of about 15 min on foot, with community residents as the service object, and is designed to meet the basic consumption and quality consumption needs of residents.

Research purpose. Urban infrastructure-related research has long been a subject of study by scholars from a variety of backgrounds. Researchers in urban planning have mostly focused on the efficiency of connections between urban systems. Scholars from a sociological background mainly focus on analyzing the causes and mechanisms behind social phenomena. Experts who have a legal background may focus on analyzing the rationality of policies and regulations.

Specifically, for evaluating the equity of parkland, urban planners concentrate on the allocation of space and its efficient use. Sociologists focus on equal access to parks for different groups. Researchers with a legal background focus on the optimization of parkland policies. There may be differences in the focus and purpose of research based on the researchers’ professional backgrounds.

Therefore, the purpose of this study is to analyze the equity of urban parkland layout through an interdisciplinary perspective. With reference to previous studies, the process equity was quantitatively calculated by drawing on the accessibility theory, which was commonly adopted in urban planning. In the outcome equity, the human concern in sociology was involved, and indicators such as income and age were introduced. As part of the cause analysis and optimization strategy section, existing policies and regulations were interpreted, and suggestions were made. Overall, the research objective is to construct an interdisciplinary evaluation framework of urban parkland equity to facilitate researchers from different backgrounds to carry out integrated studies.

Literature review. Parkland equity originates in the Environmental Justice Movement in the US (Egoz and De Nardi, 2017). In the allocation of public space, equality has been described as a fundamental requirement for equitable and sustainable urban development (Delamater, 2013), while urban park space is an essential component (Wan et al., 2012).

Research on parkland equity has gone through an early stage of geographical parity, which emphasizes the parity of urban park space in terms of geographic spatial distribution and focuses on the parity of green space area and quantity. The actual convenience of park space used by residents was not clearly reflected. Subsequent studies evolved into spatial equity, i.e., emphasizing the spatial equity of green space per capita and introducing Accessibility, which was the relative or absolute ease with which a person can overcome a variety of obstacles to reach a destination (Nesbitt et al., 2019). Since then, Green Space Accessibility measurement models have been improved and the accuracy of methods has been increased. Methods such as Buffer Analysis, Cost Distance Analysis, Gravity Model, Network Analysis, Two Step Floating Catchment Area Method (2SFCA), and Three Step Floating Catchment Area Method (3SFCA) have

emerged (Agyeman et al., 2002; Wolsink, 2016; Hansen, 1959; Fan et al., 2017; Xu et al., 2017; Wei, 2017).

Accessibility measurement models are about the difficulty of access, focusing on the process and opportunity. The research method based on Accessibility measurement models is the mainstream of green space equity research nowadays. It has been proven to be an effective quantitative assessment of spatial equity due to its easy operation and accurate results (Delamater, 2013; Wan et al., 2012; Nesbitt et al., 2019; Jennings et al., 2012). Nevertheless, it has been found that there are still dilemmas in the interface between accessibility evaluation and decision-making on the parkland layouts (Kuang et al., 2022). These methods can only be evaluated from a relatively rough perspective, treating the population as a whole. Thus, they disregard the differences in demand for parkland space among groups such as age, gender, and income in reality.

Currently, research on park space equity has been combined with social attributes, such as the Gini Coefficient, the Lorenz Curve, and other measures (Kabisch and Haase, 2014). It is not absolute equity that should be pursued in urban development, but relative equity within social relationships, which must be measured in a historical and dynamic manner (Zhou, 2020), reflecting perfection and progress. Research in developed countries has focused on the effects of race, color, income, age, and gender on the equity of urban green space (Barbosa et al., 2007; Cohen et al., 2012; Wende et al., 2012; Rigolon et al., 2018; Reyes et al., 2014).

China's urban green planning and construction process traditionally used three equity indicators to measure green space in urban parks: area, green coverage rate, and green space rate (Wei et al., 2019). Some scholars argued that neither of these indicators can reflect residents' access to green space nor their spatial distribution (Wang et al., 2004; Yu et al., 1999; Luo et al., 2022). Using landscape accessibility as an index, Yu Kongjian evaluated the service function of urban green space systems for citizens in Zhongshan City. Since then, many scholars have been exploring the equity of urban green space from the perspective of accessibility (Yin et al., 2008; Li and Liu, 2009; Yin and Xu, 2009; Jiang et al., 2010; Niu and Tang, 2021; Cao et al., 2022).

Contemporary research on urban green space equity has involved social equity, which usually contains the capabilities and needs of each social group. According to these researches, urban public services should be targeted towards specific groups (Tang and Gu, 2016; Che et al., 2020; Cao et al., 2022; Bryant and Delamater, 2019). More attention should be paid to the elderly or the kids who have special demands to green spaces in Landscape Planning (Zhou and Wang, 2023; Wang et al., 2021; Feng and Lin, 2022; Fang et al., 2015), from the perspective of supply matching. The theory of supply and demand was thus introduced to accurately evaluate the layout of green spaces, which focuses on the distribution outcome (Du and Jin, 2022; Zhou and Huang, 2019; Mu et al., 2019; Wang et al., 2023; Xu et al., 2022).

The concept of the Living Circle was first introduced in Japan in 1965 to rationalize infrastructure and public service facilities (Jun, 2004). As far as spatial patterning is concerned, the Living Circle considered industry, greenery, and transportation, focusing on rail, bus, bicycle, and walking as a framework (Fan and Cheng, 2022; Chen, 2011). In the early 1990s, China pulled in the concept of the Living Circle (Cheng, 2018). Shanghai 2035 Master Plan introduced the 15-min Living Circle as the first spatial unit concept in China (Editorial Department of Urban Planning Forum, 2020). At present, the 15-min walking distance of residents is used as an important indicator to evaluate the service function of public facilities, known as the 15-min Living Circle.

Using the cumulative opportunity method, Junpeng Zhao explored the relationship between the facility accessibility and the

matching radius of the Living Circle (Zhao et al., 2021). From the perspective of supply and demand correlation, scholars explored the divergence between the spatial supply of community living circle service facilities and residents' demand (Tang and Gu, 2016). Guo Rong et al. proposed a strategy for the optimization of the 15-min community Living Circle and walking network in Harbin (Guo et al., 2019). In the context of building elderly-, child-, and disabled-friendly cities, some scholars have also explored the elderly living circle and facility configuration requirements (Zhao et al., 2022; Zhang, 2020). At present, the accessibility calculation method has been widely used in the delineation of the Living Circle and the configuration of public facilities (Wan et al., 2022; Wu et al., 2021). The study of green space equity has shifted from land equity to equity of people. However, there is still a lack of studies that analyze the equitable layout of urban parkland from the perspective of process outcome and the construction of community Living Circles (Wüstemann et al., 2017).

Analysis of current research on parkland equity reveals that they are primarily concerned with three aspects.

1. Evaluating the spatial equity of parkland through different methods and the commonly used indexes were based on accessibility.
2. Evaluating the benefits of urban parkland from the perspective of social equity.
3. Investigating the uneven phenomenon of various types of parkland, analyzing the causes, and proposing optimization strategies.

Despite the wide range of research dimensions on parkland equity in China, a systematic evaluation framework was lacking.

Research innovations and framework. Based on the literature review, it has shown that most evaluation methods on urban green space equity were limited to one dimension, ranging from quantitative calculations based on the number or area of parks to spatial analyses of accessibility value and evaluations of the availability of parkland by a specific group. While most of these evaluation methods were of progressive importance for parkland equity, it was difficult to evaluate at a systemic level and to propose optimization strategies in conjunction with existing policies.

Therefore, the following two research questions have been raised:

1. What can be done to measure green space equity in high-density cities in a more systematic manner?
2. How can practical optimization strategies be developed through systematic evaluation?

The purpose of this study is to conduct a possible research methodology to address these two questions. As a result, the key innovation lies in the establishment of an evaluation framework and method tailored for assessing the equity of parkland in high-density urban areas. This approach comprehensively considers equity in both process and outcome. By integrating perspectives from multiple disciplines, it can provide a theoretical basis for equitably allocating parkland, and for optimizing urban green space planning and management. The aim is to rationalize and equalize the spatial layout of urban parkland, thus promoting the equitable enjoyment and balanced distribution of green space resources. This study is highly applicable and can be extended to other high-density cities in China for comparative research.

To be specific, this paper calculated the equity value of urban parkland within a 5, 10, and 15 min walking distance of the living area from the perspective of process and outcome, taking the Central Area of Zhengzhou as an example.

Spatial equity and social equity were calculated respectively in terms of process and outcome. Traditional equity calculations, which are based on accessibility focused on the quantity and spatial dimensions, but ignored elements such as the age composition. Different people have varied needs for green space and preferences. The accessibility-based calculation treated the population as a whole, thus missing the study of social attributes. In this paper, the relationship between parkland demand and supply for different age groups was investigated using Zone Entropy calculations.

The traditional 2SFCA calculation ignored human preference and competitive relationships. People do not necessarily prefer parks that are close to them but may choose parkland that are larger and have better infrastructure (Tao and Cheng, 2016; Wan et al., 2012; Wang et al., 2015). Therefore, this paper utilized 3SFCA as a measurement to calculate the accessibility value. Then the E_i value was calculated, which was used to characterize the spatial equity. Combined with Zone Entropy calculations, the evaluation was carried out from the level of spatial and social allocation (Zhang et al., 2022).

Both walking and bicycling were chosen as the measurements in this study. Travel time was used instead of distance to avoid the bias caused by calculating the geometric distance between two points. Therefore, the research method adopted in this study has further generalization value. The research framework of this paper is shown in Fig. 1.

Methods

Research area. The research area is the Central Area of Zhengzhou, including Zhongyuan District, Erqi District, Guancheng District, Jinshui District, and Huiji District, a total of five areas with 1017 km², shown in Fig. 2. Data from the Sixth National Census in 2010 showed that Zhengzhou City had a total of 8,626,505 people. Zhengzhou has a Temperate Continental Monsoon Climate characterized by four distinct seasons. To be specific, Zhengzhou has a warm climate in the spring and a cool climate in the fall, with a 30-year average temperature of 14.7 °C³, making it suitable for walking and cycling.

Zhengzhou is a supercity and the capital of the Henan Province, which is also a National Central City explicitly supported by the state for construction⁴. National Central Cities are the highest level of China's urban system planning for cities. Zhengzhou is located in the Central Plains region and is a national transportation hub for public transportation.

Research data

Parkland space. According to the previous studies, and considering the availability of data, this paper used parkland data as the supply side (Wei et al., 2019; Niu and Tang, 2021). Based on the Urban Green Space Classification Standard, parkland spaces in the research area were divided into Comprehensive Parks (>10 hm²), Community Parks (1–10 hm²), and Pocket Parks (≤1 hm²). Previous studies have used the geometric center of parks instead of park entrances and exits (Zhou et al., 2013), which may have a relatively high influence on the results of large parks. In this study, a Baidu map coordinate picker was used to obtain the coordinates of park entrances and exits. It was used to calculate accessibility with the actual park entrance and exit locations to improve accuracy. The data is shown in Fig. 3.

Residential areas and population. Using the data of the Sixth China Census⁵, the population of the streets in the research area can be obtained, shown in Fig. 4. Through the API port of Gaode Map, the data of residential area points were obtained. The center point of each residential area was extracted as the center of population distribution to obtain the residential area distribution

map. House price data was obtained through Housing World and Anjuke, shown in Fig. 5. The Interpolation Analysis of house prices by the inverse distance weight method can yield the results of house prices in the research area, shown in Fig. 6.

The level of residents' population largely reflects the life quality of the occupants (Tu et al., 2019; Abercrombie et al., 2008; Jones et al., 2015). House prices potentially reflect the consumer purchasing power of residents. This paper utilized house price data to characterize the level of economic status of the residents. Based on the house price, the residential area and residents' income were divided into five levels using the Natural Interruption Point Method (Table 1), which represents the residents' economic status level.

Since it is hard to obtain accurate population of each residential area directly, the data was estimated from the total population (Wu et al., 2016). The formula for calculating the population of a single residential area is

$$R_p = \frac{R_A}{D_A} \times D_p \quad (1)$$

D_A and D_p indicate the residential area and the total area, while R_A and R_p indicate the population of the residential area and the total population respectively.

Road network. The road network data was based on Open Street Map (OSM) data⁶. Based on 5-, 10- and 15-min Living Circle, the speed was assigned to two different modes of transportation: walking and cycling. The average speed of walking and cycling is 5 and 10 km/h, respectively. When calculating the accessibility of parkland spaces, the time cost in road corners, intersections, and other areas was simulated using GIS tools.

Research calculation process

Process equity evaluation based on spatial accessibility. The first step was to calculate the supply–demand ratio (R_j) of 5, 10, 15 min of walking and 5, 10, 15 min of cycling by using 3SFCA.

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \leq d_0\}} D_i \times G(d_{ij}) \times W(d_{ij})} \quad (2)$$

In the second step, the gravity distance decay function $G(d_{ij})$ and the selection weight function $W(d_{ij})$ of the population were calculated, respectively.

$$G(d_{ij}) = \begin{cases} dij^{-\beta}, & dij \leq d_0 \\ 0, & dij > d_0 \end{cases} \quad (3)$$

β represented the degree of attenuation, for plain cities and metropolises, the general value is 1 (Lu and Li, 2019; Xu et al., 2017). $W(d_{ij})$ represented the relationship between choices and competitions of people for parkland, and its calculation formula was as follows:

$$W_{ij} = \frac{G(d_{ij})}{\sum_{i \in \{d_{ij} \leq d_0\}} G(d_{ij})} \quad (4)$$

The third step was to calculate the accessibility value of the residential area.

$$A_i = \sum_{i \in \{d_{ij} \leq d_0\}} R_j \times G(d_{ij}) \times W(d_{ij}) \quad (5)$$

The last step was to calculate the equity value:

$$E_i = \frac{\max(R_j)}{\max(A_i)} \times A_i \quad (6)$$

E_i was the equity value of each residential area (Taleai et al., 2014). $E_i > 1$ indicated that supply was greater than demand. $E_i \leq 1$ indicated that supply and demand were relatively

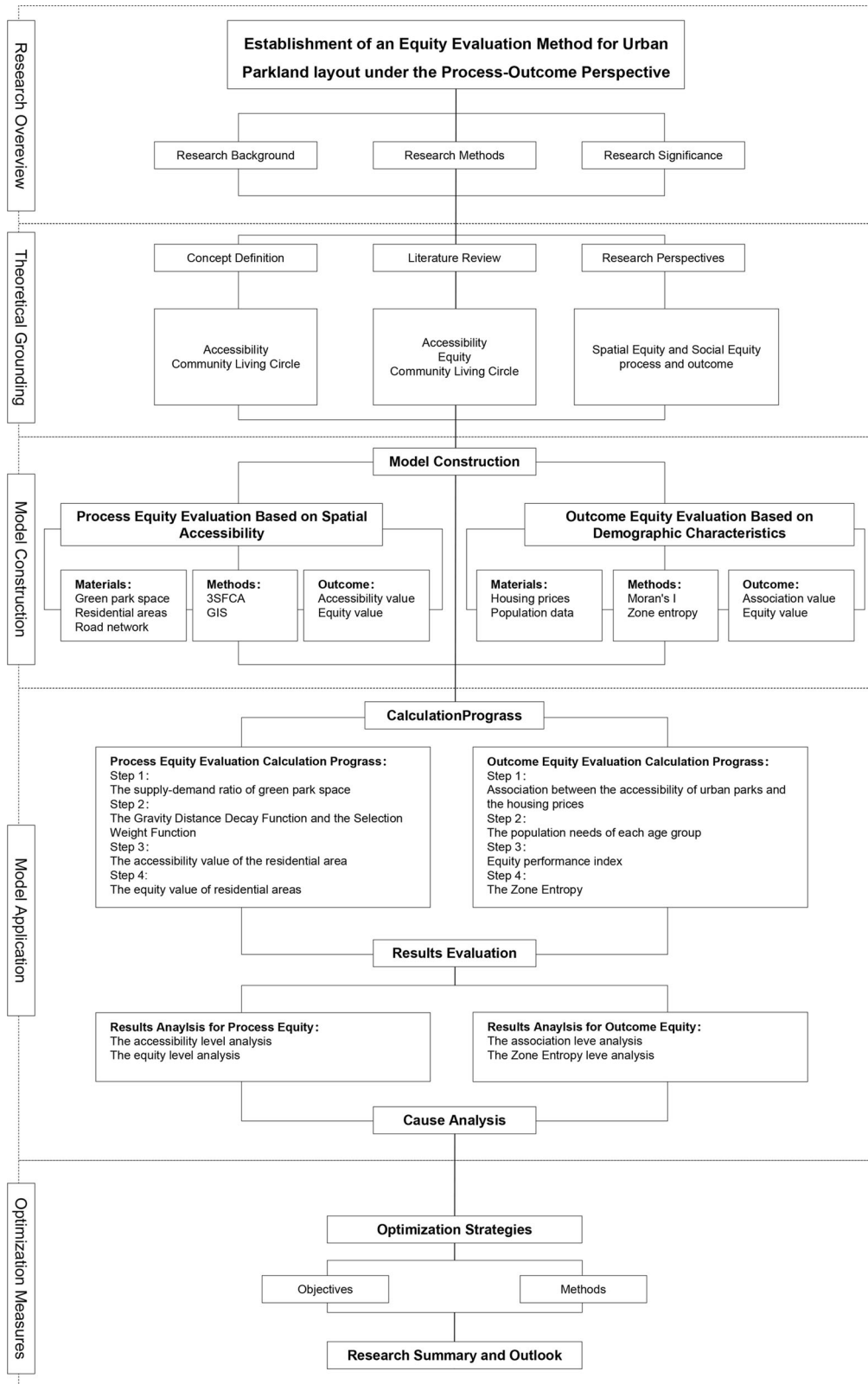


Fig. 1 Research Framework.

balanced or supply was less than demand. According to the E_i value, the supply level of parkland was divided into six grades I–VI, which were as follows (Zhang et al., 2022): I No Supply Service ($E_i = 0$), II Lack of Supply ($0 < E_i < 0.25$), III Insufficient Supply ($0.25 \leq E_i < 0.50$), IV Balanced Supply ($0.5 \leq E_i < 0.75$),

V Sufficient Supply ($0.75 \leq E_i \leq 1.00$), VI Saturated Supply ($E_i > 1.00$).

The process equity level was established by measuring the supply and demand levels in different residential areas. It was divided into the following five levels: Seriously Inequality (I and II), Relatively



Fig. 2 Map of the Research Area.

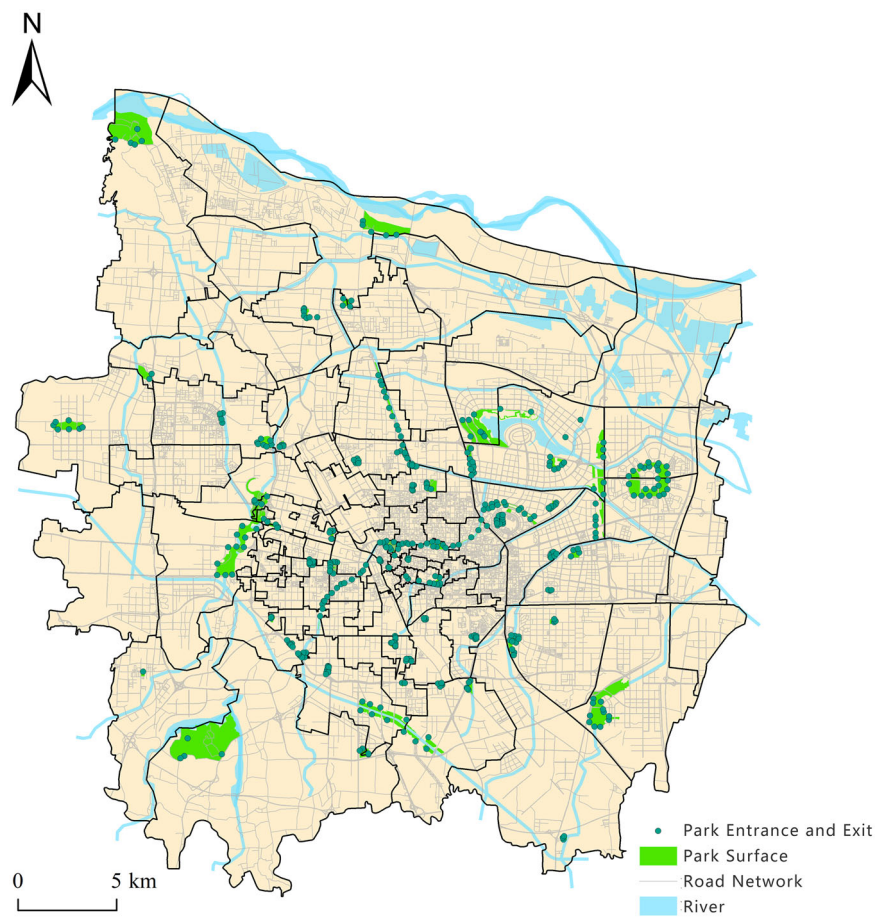


Fig. 3 Map of Park Entrances and Exits.

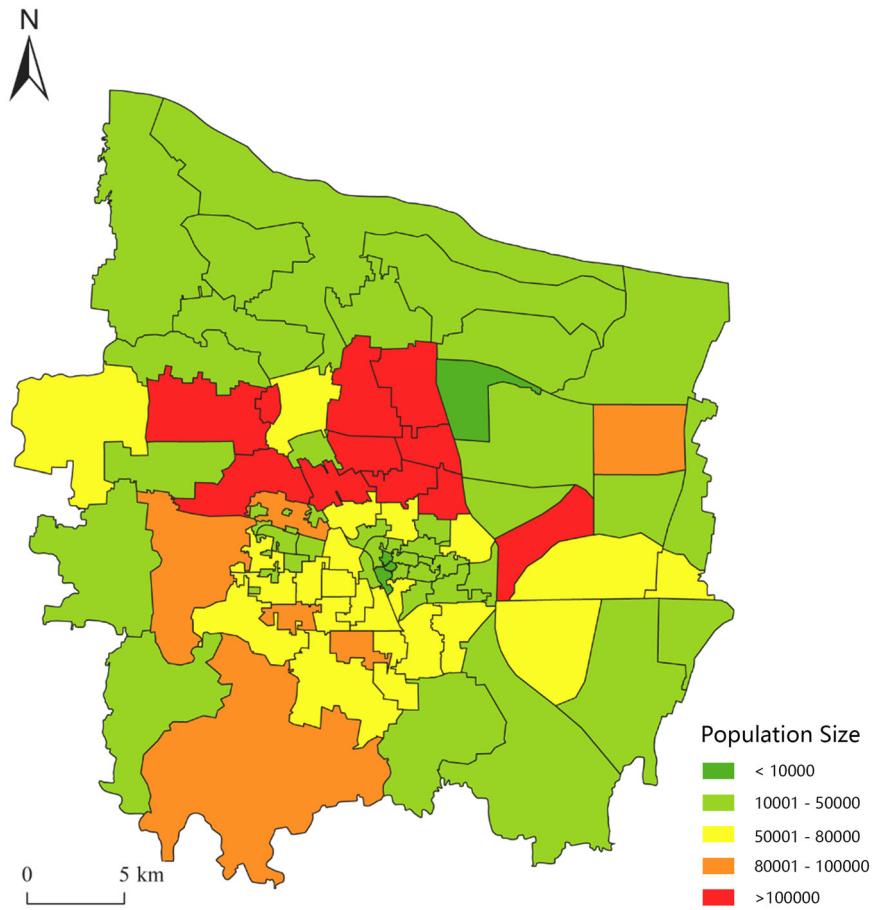


Fig. 4 Map of Street Level Population.

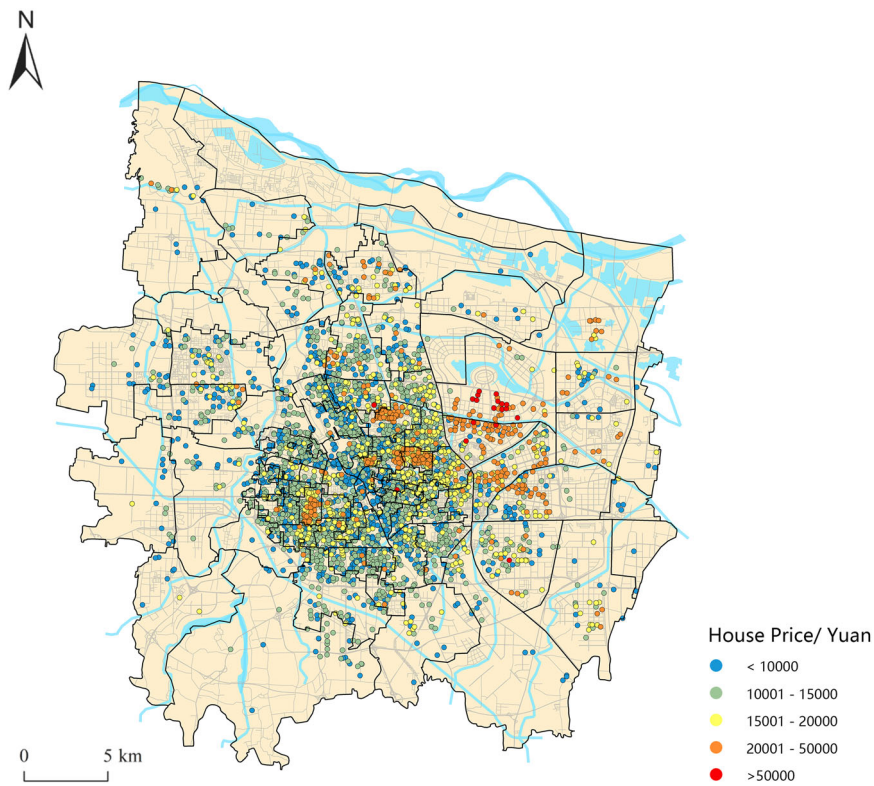


Fig. 5 House Price of Residential Area Level.

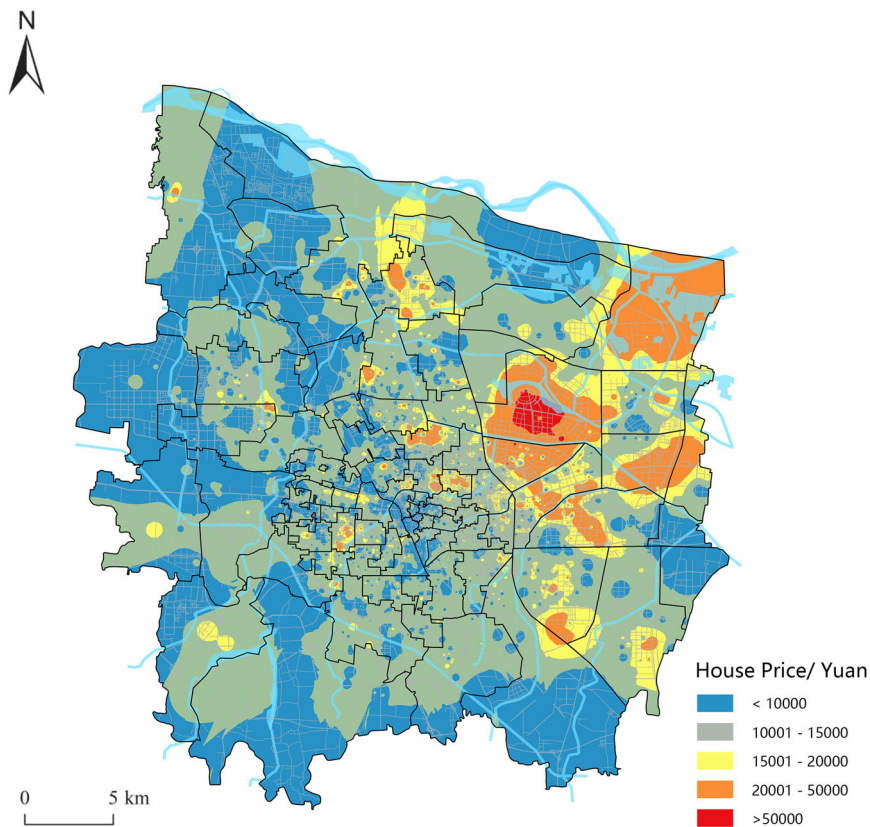


Fig. 6 The Visualization Results of House Price.

Inequality (III), Equality (IV), Relatively Equality (V), and Inequality (VI).

Outcome equity evaluation based on demographic characteristics. Moran’s *I* was used to assess the association degree between accessibility and income, which was calculated as

$$I_{xy}^i = Z_x^i \sum_{j=1}^n M_{ij} \times Z_y^i \quad (7)$$

Moran’s *I* resulted in five categories: HH, LL, HL, LH, and Non-significant. The HH category indicated high parkland accessibility and high house prices, which represented a balanced residential area with high parkland accessibility and high economic status. The LL category represented a lagging residential area with low parkland accessibility and low economic status. The LH category represented low green space accessibility and high economic status. The HL category represented high green space accessibility and low economic status. The non-significant type indicated that the spatial relationship between park accessibility and house price was not significant.

Elder people and children are vulnerable groups in the study of social equity. Besides, the elderly and children tend to use parks more frequently and have relatively diversified needs (Jiang et al., 2010; Li, 2020; Chen and Ma, 2022). Therefore, the park layout needs to be tilted toward vulnerable groups (Guo et al., 2019). Based on the age differences in residents, equity evaluation was conducted as follows:

The first step was to determine the needs of each age group.

Through the Sixth Census data, the population data of 0–14 years old children, 15–65 years old adults and elder people over 65 years old were obtained. To eliminate the impact of the overall level difference on the demand force of different ages, the data was normalized by range standard deviation. The calculation

formula was as follows:

$$N_i = \frac{F_i - F_{\min}}{F_{\max} + F_{\min}} \quad (8)$$

N_i represented the demand index of age. F_i represented the population of the group. F_{\max} and F_{\min} represented the maximum and minimum population of group i , respectively.

In the second step, the equity performance index was calculated. It can measure the gap between the access level of various groups in society and the average access level of society, which is an indicator of the overall equity of each age group without taking into account spatial differences. The equity performance index was calculated for each age group with the following formula:

$$C = \left(\frac{\sum_{i=1}^n N_i \times x_i}{\sum_{i=1}^n P_i \times x_i} \right) / P \quad (9)$$

C represented the equity performance index of one age group. N_i represented the normalized value of the population. x_i represented the average urban parkland access capacity of street i . P_i represented the normalized value of the resident population. As a percentage of the total resident population, P represents the number of residents in that age group.

As a result, when $C > 1$, it means that the age group has a higher urban parkland access capacity than the average. $C < 1$ means that was lower than the average. The more the value of C converges to 1 means the more equitable of that age group.

The third step was to calculate the Zone Entropy (Zhang et al., 2012). To further evaluate the relationship between the distribution of parks and population, it was clarified with calculation. The formula was as follows:

$$Q_i = \frac{x_i / D_i}{X / D} \quad (10)$$

Table 1 Residential area classification.

Level	Class 1	Class 2	Class 3	Class 4	Class 5
Range of House price (yuan/m ²)	>50,001	20,001-50,000	15,001-20,000	10,001-15,000	<10,000
Residential class	Villa area/upscale neighborhoods	Middle to high-grade neighborhoods	Mid-range neighborhoods	Low- and mid-range neighborhoods/old neighborhoods	Low-grade neighborhoods/bungalows
Residents' income	High income	Middle to high-income	Middle Income	Low to middle-income	Low income

Q_i was the zone entropy of street i . D_i represented the population size of a certain age group. X represented the sum of urban park acquisition capacity of all street in the study area. D represented the total population of that age group.

When $Q_i > 1$, it represented the supply capacity of parks was higher than the demand of that age group, and the opposite was true when $Q_i < 1$. According to the Q_i values, the results were classified into six levels, namely: much lower than the overall level (0-0.25), lower than the overall level (0.25-0.5), Slightly Lower than The overall level (0.5-1.0), higher than the overall level (1.0-2.5), Slightly Higher than The overall level (2.5-5), and much higher than the overall level (>5) (Zhu, 2020).

Results

Accessibility and equity results. Under three-time thresholds, respectively, the overall walk and bicycle equity in the Central Area of Zhengzhou was inferior, as shown in Figs. 7 and 8.

The total percentages of residential areas that were Inaccessible, Poor Accessible and Relatively Poor Accessible by walking for 5, 10, and 15 min were 95.9%, 90.0%, and 86.2%, respectively. Overall, 87.3%, 84.5%, and 81.5% of residential areas were Inaccessible, Poor Accessible, or Relatively Poor Accessible by bicycle for 5, 10, and 15 min, respectively. More than half of the residential areas had poor accessibility to urban parks.

As shown in Figs. 9 and 10, the overall walking equity in the research area was poor under each of the three-time thresholds. The total percentages of Equitable and Relatively Equitable with 5, 10, and 15 min walking were 0.83%, 2.42%, and 6.26%, respectively. There was a total percentage of Equitable and Relatively Equitable with 5, 10, and 15 min by bicycle of 4.80%, 13.38%, and 24.77%, respectively. In more than half of the residential areas, parks were distributed in an inequitable manner. The overall equity within the study area improved with the increase in time threshold.

Moran's I result. According to the Moran's I Index calculation (Table 2 and Fig. 11), the share of HH varies between 2.21% and 3.12% for a 15-min walk and 15-min cycle ride, respectively, which is concentrated in Longhu Street, Longzihu Street, Ruyi Street, Shangdu Road Street, and Boyue Road Street. There is a 1.47% and 1.86% share in the HL region, a 17.18% and 16.95% share in the LH region, and a 7.75% and 8.85% share in the LL region. There is no clear pattern of distribution for the above three types. However, the percentage of area in the category non-significant exceeds 70%.

Zone entropy results. According to the results of the equity performance index calculation (Table 3), the equity performance index for the group of children aged 0-14 was 0.657, and the level of access to urban parks was much lower than the average. For the group aged 15-64, the equity performance index tends to be close to 1, with the largest population share being close to the average. The equity performance index for the group of people aged 65 and older was 1.107, slightly higher than the average level.

The results of Zone Entropy of each street within the study area were shown in Fig. 12 and Table 4. Among them, five streets, namely, Xincheng Street, Guxin Town Street, Longhu Street, Songshan Street, and Longyuan Street, were much higher than the average. Zhongyuan West Street was relatively higher than the overall level. Houzhai Street, Chaohe Street, and Boxue Street were slightly higher than the overall level. Overall, there were a total of 9 streets higher than the average, accounting for 11.25%. The number of streets that were lower than the overall level was 71, accounting for 88.75%.

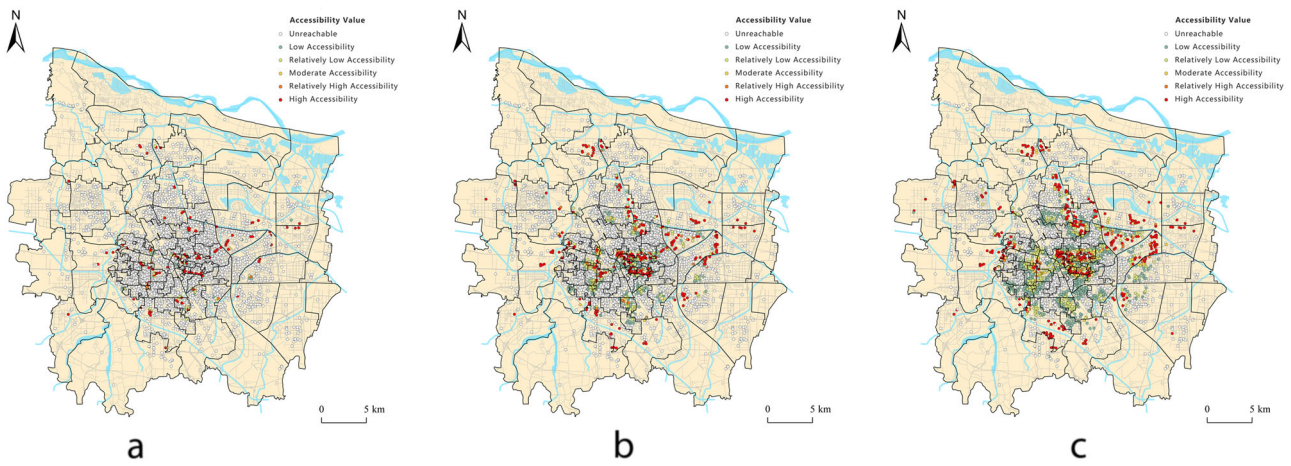


Fig. 7 Walking Accessibility Results Map. Walking accessibility results: (a) 5 min walk; (b) 10 min walk; (c) 15 min walk.

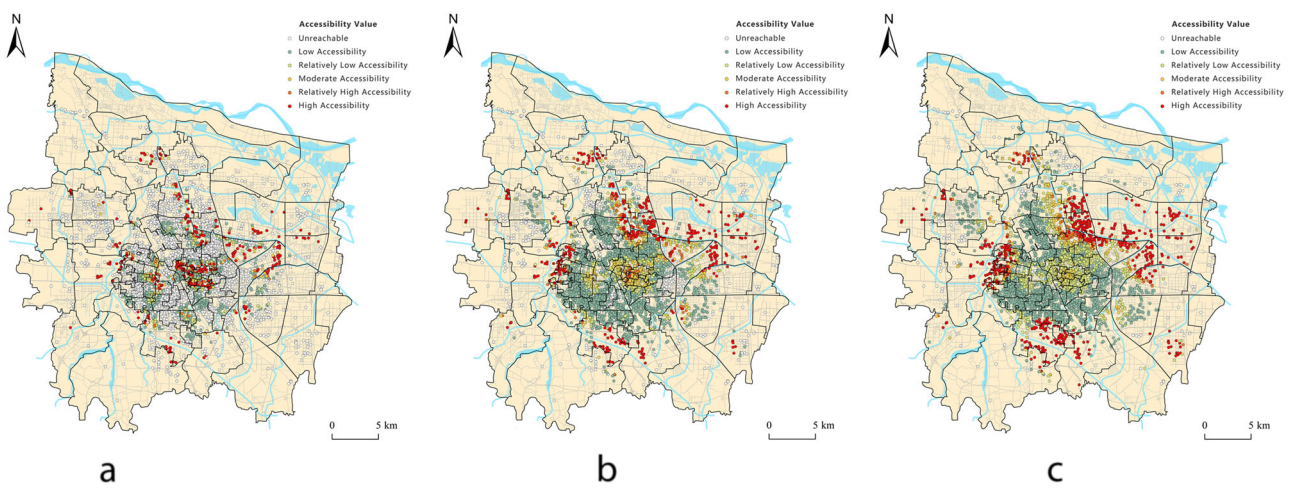


Fig. 8 Bicycle accessibility results: (a) 5 min by bike; (b) 10 min by bike; (c) 15 min by bike.

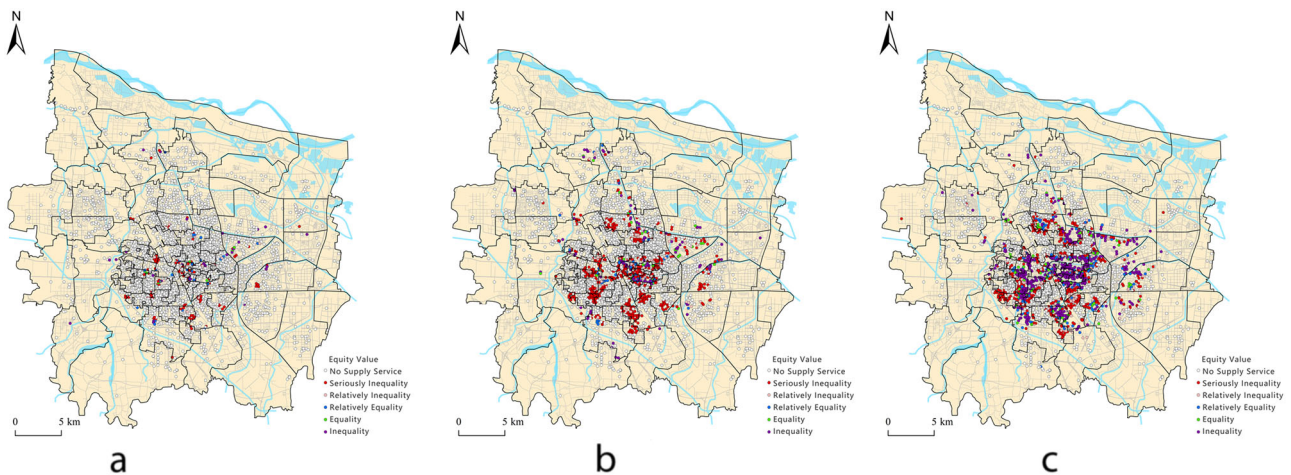


Fig. 9 Walking Equity Results Map. Walking equity results: (a) 5 min walk; (b) 10 min walk; (c) 15 min walk.

According to the calculation results (Fig. 13), there were 9 streets with Zone Entropy higher than the average for the 0–14 age group children, accounting for 11.25%. 9 streets had Zone Entropy levels higher than the overall level for the 15–64 age group, accounting for 11.25% of the total. There were 10 streets

with Zone Entropy higher than the overall level for the 65+ age group, accounting for 12.5%.

In all three age groups, 9 streets had Zone Entropy values higher than the average, namely New Town Street, Guxing Town Street, Longyuan Street, Longhu Street, Songsshan Street,

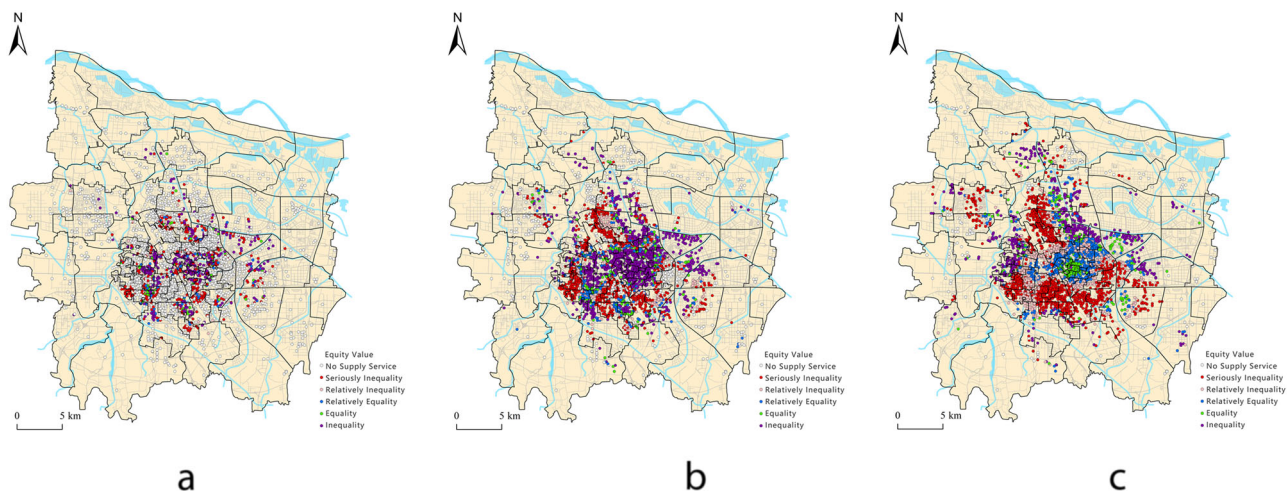


Fig. 10 Bicycle Equity Results Map. Bicycle equity results: (a) 5 min by bike; (b) 10 min by bike; (c) 15 min by bike.

Table 2 Five categories of residential area proportion.					
	Non-significant (%)	HH (%)	LH (%)	LL (%)	HL (%)
Walking 15 min	70.29	2.21	17.18	8.85	1.47
Bicycle 15 min	70.33	3.12	16.95	7.75	1.86

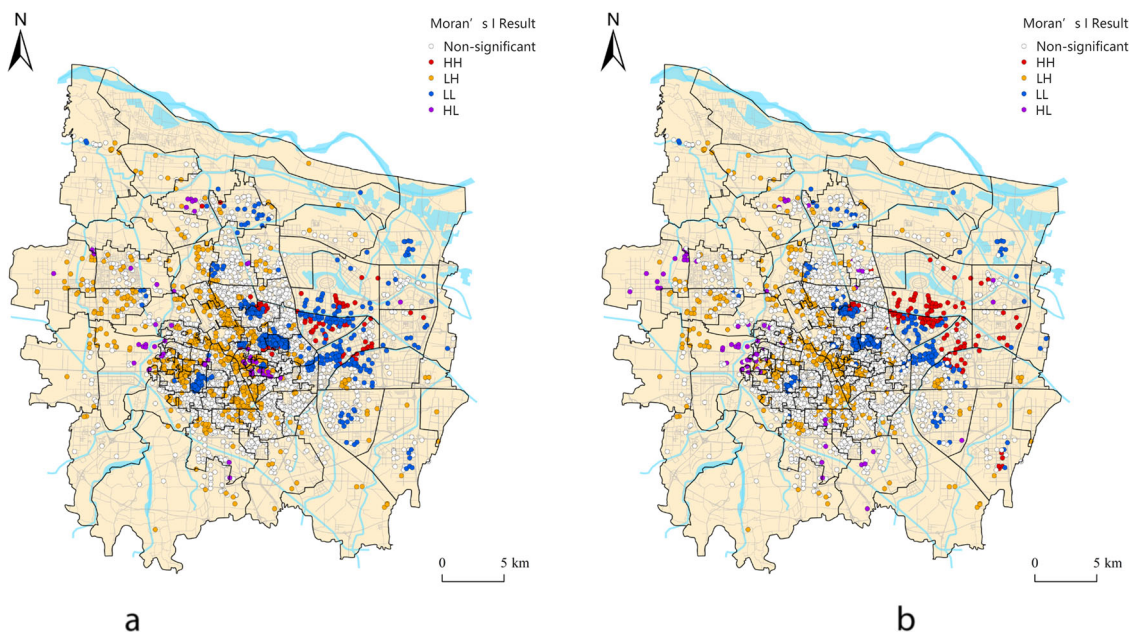


Fig. 11 Moran's I Result. The degree of association between the accessibility of urban parks and the housing prices: (a) 15 min' walk; (b) 15 min by bike.

Zhongyuan West Street, Boxue Street, Houzhai Street, and Chaohe Street. As for Fengqing Street, only the 65+ age group Zone Entropy was higher than the overall level.

Discussion

Equity discussion based on process perspective. Based on the process perspective, the results of accessibility and equity calculations illustrated that the overall accessibility and equity of parkland in the Central Area of Zhengzhou were inferior, with a large number of blind service areas and serious polarization.

In terms of walking, at the 15-min time threshold, the residential areas with relatively good walking accessibility were

concentrated in the core areas of the study area. These residential areas were mainly located on Dongddajie Street, Xidajie Street, Renmin Street, Mingong Street, Duling Street, Dashiqiao Street, Boxue Street, Ruyi Lake Street, Longhu Street, and Culture Street, with no obvious distribution pattern. The overall equity of walking as a mode of travel within the study area increases as the time threshold increases. However, there is a high degree of polarization under the 15-min walk time; more than half of the neighborhoods were located in service blind areas. Some of the residential areas located in the central region were saturated with parkland supply, leading to inequitable walking equity results.

In terms of bicycle travel, the residential areas with relatively good equity under the 15-minute time threshold were concentrated in the northeast, south, and west. These residential areas were mainly concentrated in Longzihu Street, Longhu Street, Ruyihu Street, Boxue Street, Guoji Street, Beilin Street, Fengyuan Street, Culture Street, Songshan Street, Eighteen Mile River Town Street, Jinguang Street, Sanguanmiao Street and Tongbai Street. The distribution was characterized by large strip parks or riverfront parks along the Dongfeng Canal Riverfront Park, the South-North Water Transfer Ecological Park, the Xiliu Lake Park, and the Zhengzhou High-Speed Rail Park. However, due to low population densities, the walking equity results of residential areas adjacent to strip parks or riverfront parks experience inequitable.

Due to the extreme saturation of parkland supply at the 10-min time threshold, residential areas located in the center area

experience inequities. At the 15-min time threshold, the calculated search area was expanded to include more settlements with access to parkland, and the residential areas instead showed better equity results. Under the 15-min time threshold, overall bicycle accessibility and equity were higher than walking, and polarization had been reduced. Objectively, the bicycle travel rate was greater than walking. Under the 3SFCA, the search area and radius were expanded. As a result, the opportunity for parkland accessible to each residential area would be improved (Kuang et al., 2022; Zhang et al., 2022).

The areas with good walking accessibility or equity in 15 min were concentrated in the central, and an agglomeration phenomenon occurred. The high commercial value of the central area and the abundant green space resources have resulted in a saturated supply, causing inequities to emerge.

Under 15-min bicycle travel mode, the search radius increased and parkland service areas increased. The supply of parkland in the central area was balanced, indicating an equitable or relatively equitable phenomenon. The aggregation phenomenon in the central area of the study area diminished, and the calculated overall polarization degree decreased compared to the results of the walking mode. As a result, the overall park space equity was relatively better.

Overall, accessibility and equity within the study area increased with increasing temporal thresholds, with relatively higher accessibility in residential areas adjacent to riverfront or strip parks. Population density had a great impact on the equity of parkland. Some areas with lower population density and better accessibility have extremely high equity values due to the

Table 3 Population equity performance index for different age groups.

Age group	Population	Proportion (%)	Equity performance index
0-14	680,293	14.7657	0.667
15-4	3,630,000	78.7892	1.003
65 and older	294,075	6.3829	1.107
	4,607,225	100	1

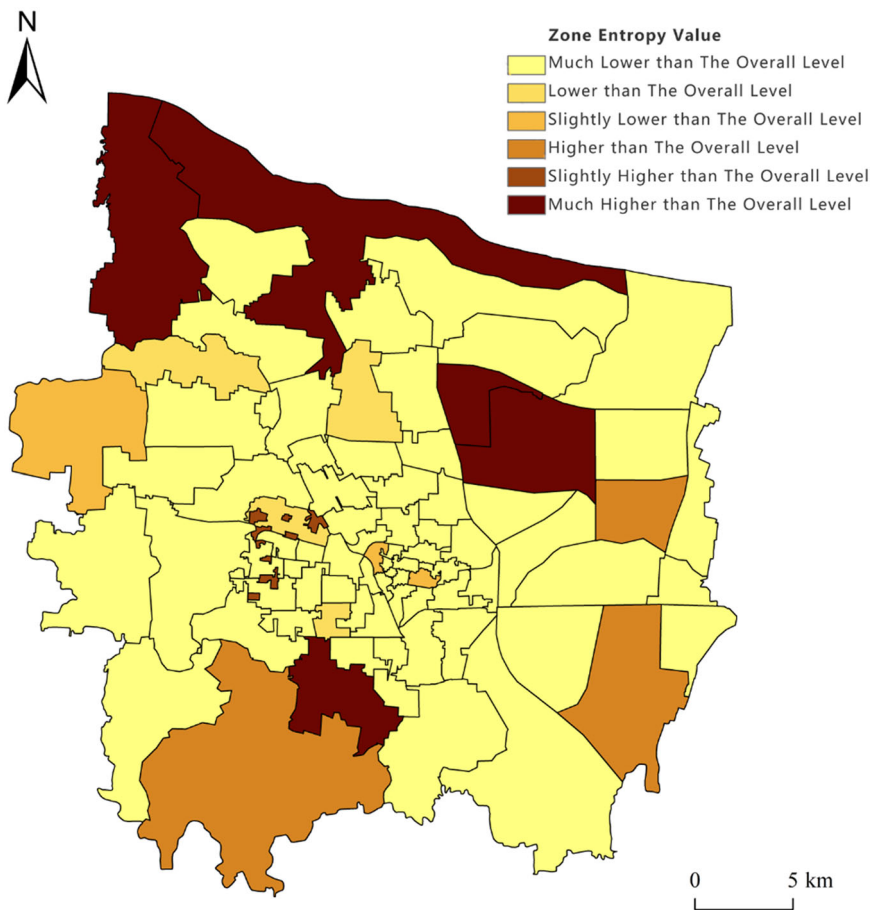


Fig. 12 The Street Level Zone Entropy Map.

Table 4 The results of the zone entropy of the total population of each street.

Equity performance index level	Region	Number of streets	Proportion (%)
Much lower than the average	(0-0.25)	64	80
Relatively lower than the overall	(0.25-0.5)	4	5
Slightly lower than the overall level	(0.5-1.0)	3	3.75
Slightly higher than the overall level	(1.0-2.5)	3	3.75
Relatively higher than the overall level	(2.5-5)	1	1.25
Much higher than the average	(>5)	5	6.25

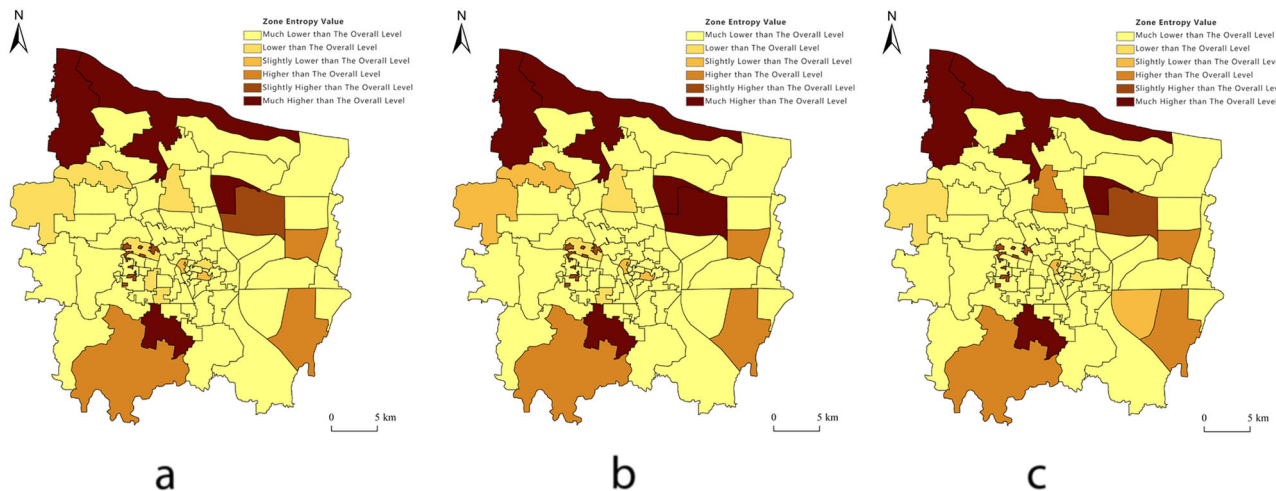


Fig. 13 Zone Entropy Map of Different Groups. Different age group zone entropy of each group: **a** 0-14 age group of children; **b** 15-64 age group; and **c** 65+ age group of elderly people.

saturation of green space resource supply, leading to polarization of the calculation results.

Beijing, Wuhan, and Shanghai, as mega-cities, also have polarized distribution of parkland resources (Wei et al., 2019; Kuang et al., 2022; Zhang et al., 2022). In Beijing, there are many historical sites, which are concentrated in the third ring and the northwest suburbs. A cultural park converted from a historical or cultural site has the characteristic of covering a large area and being concentrated in location. The Summer Palace, the Yuanmingyuan Heritage Park, and the Xiangshan Park are concentrated in the northwest suburbs, while the density of population in the area is relatively low, leading to extreme accessibility calculation values (Wei et al., 2019). There is a mismatch between the population demand, the number of parks, and the parkland service capacity in Wuhan, resulting in the saturation of parkland resources and a “serious inequity” in some parks (Xu et al., 2017). In the Central Area of Shanghai, some spatial units have a higher level of public green space service than others, but their resident population density is much higher, resulting in a relatively lower level of service.

The existing parks with large areas in the study area are Renmin Park and Zijingshan Park, both of which were built in the 1950s. Zijingshan Park was built on the basis of the mall site and has been repaired and expanded over the years. From 2005 to 2020, the area and scale of parkland in the Central Area of Zhengzhou increased significantly, with a growth rate of nearly 200% in the number of parkland (Feng, 2022). However, according to the census data, the resident population in Zhengzhou has increased from 6.66 million since 2000 to 12.6 million in 2020, and the population density distribution showed a decreasing trend from the central area of the city to the surrounding area (as shown in Fig. 3).

The rapid expansion of the city in the last 15 years had made construction land scarce, and a larger area of parkland had been established outside the second ring road, which was spatially misaligned with the distribution of the population. Due to the continuous increase in urban population, the imbalance in the number and layout of parkland has compounded the contradiction (Wang et al., 2022).

Equity discussion based on outcome perspective. Based on the outcome perspective, the results of equity were general in the research area.

In the evaluation based on the difference in economic status, the residential areas with high house prices were concentrated in the northeastern. The correlation between the equity of urban parks and housing prices had been analyzed, and residential areas were classified into five categories. The balanced residential areas with high housing prices and high access to parkland were concentrated in Longhu Street, Ruyi Lake Street, and Sacrificial City Street, which were consistent with the distribution of high-grade and middle-grade residential areas. These areas have low population density and sufficient parkland resources. The lagging residential areas with relatively low house prices and low equity to parkland were concentrated in Ruyi Lake Street, Sacrificial City Street, and Shangdu Street.

The HL areas were concentrated in the western part of the study area. The number of LH residential areas was the least. There was no obvious distribution pattern. At the street level, in Ruyi Lake Street, Sacrificial City Street, and Culture Street, lagging and balanced areas co-existed. There was no obvious correlation between green parkland accessibility and residents’ economic level.



Fig. 14 Pearson Index Matrix. House price and equity level Pearson index matrix.

In the age-difference-based equity evaluation, the equity performance index was calculated for each age group. The results of the equity performance index reflected the gap between the ability of different age groups to access parkland and the average level.

Without considering spatial elements, the ability to access parkland was less equitable for the 0–14-year-old age group. The equity performance index was severely below the average level, with children's needs for parkland not being met. The equity performance index for the elderly group over 65 years old was slightly higher than the overall level, indicating that they have been given a tilt in parkland resources. From the overall level, the equity performance for all age groups still needs to be improved.

Using Zone Entropy to explore the relationship between demand and parkland supply, it was found that Zone Entropy varied considerably among streets. This indicated a significant spatial variation in the distribution of parkland and population among streets. The Zone Entropy of minority streets was much higher than the average, while the Zone Entropy of more than half of the streets was much lower. These streets with high Zone Entropy have a great impact on the overall results, pulling up the overall level in numerical terms.

There were cases where the total population was large, but the parkland resources were small or the opposite. The match level between parkland resources and population within the study area was inferior. Within each street, the Zone Entropy of different age groups was basically consistent with the Zone Entropy of the total population, indicating that spatial differences have a significant impact on the Zone Entropy results.

Overall, the equity evaluation based on age differences illustrated that parkland resources had been tilted toward the

elderly group. However, combined with the results of accessibility calculation at the spatial level, it can be seen that most of the residential areas had poor accessibility to parkland under the 15-minute time threshold. There were mass blind areas for services. It was hard for children and the elderly over 65 to access parkland. Therefore, the construction of the 15-min Living Circle still needs to be vigorously promoted in the future.

Conclusion

Cause analysis

Economic factor. According to relevant research, economic conditions can influence the equity of parkland to residents. Generally, higher-income correlates with better equity in green space access (Wang et al., 2022). This study represented the income levels based on the housing prices of 5164 residential communities within the study area, treating these as the independent variables. Walking equity and cycling equity within 15 min were used as dependent variables. Additionally, the study incorporated the absolute differences in walking and cycling equity to represent the disparities between these modes of transportation, namely Absolute Equity Value.

The research employed the Pearson correlation coefficient to analyze. Based on the Pearson coefficient absolute value, the degrees of correlation were generally categorized as very strong (0.8–1.0), strong (0.6–0.8), moderate (0.4–0.6), Weak (0.2–0.4), and very weak or none (0.0–0.2). Ultimately, a correlation matrix was constructed, as illustrated in Fig. 14.

Analysis indicated that the level of residents' income exhibited a very weak or no correlation with 15-min walking equity (0.0313), 15-min cycling equity (0.0652), and the absolute equity

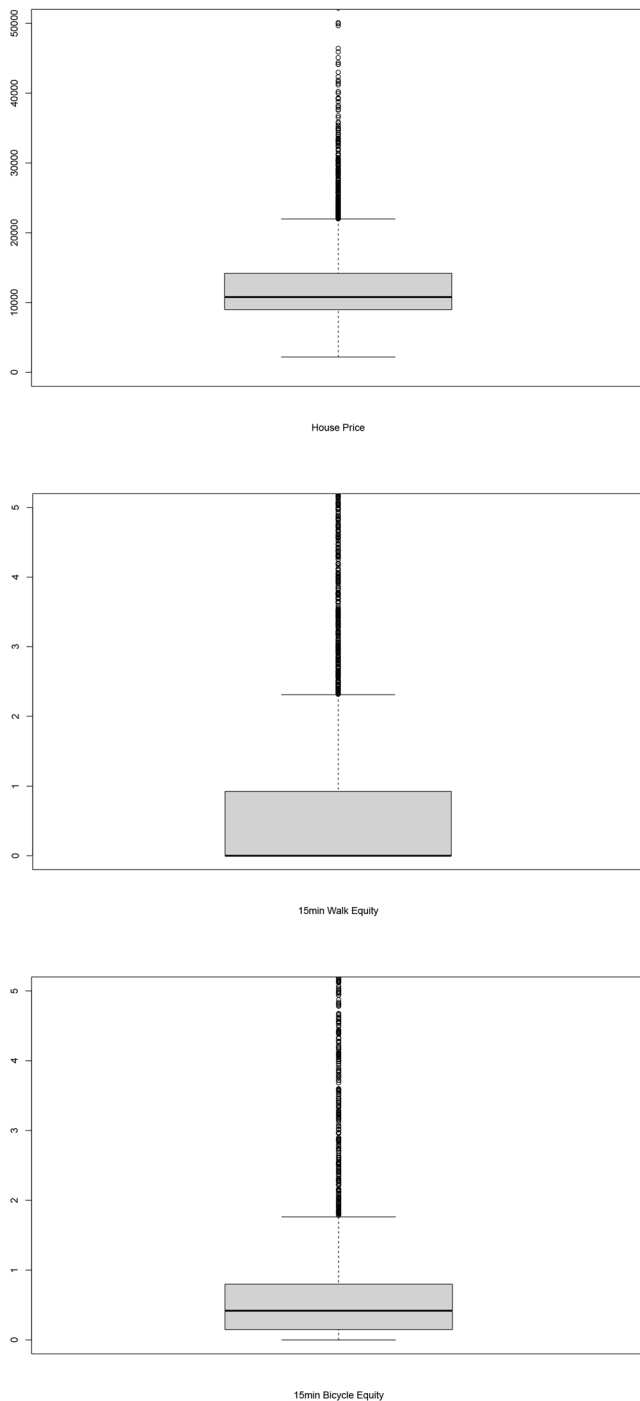


Fig. 15 Box Plot. Research key parameters box plot.

value (0.0320). These findings diverged from alternate Chinese metropolises. Prior research suggested a certain relationship between housing prices (income level) and the equity of parkland in Wuhan. Here were also studies, such as in Chengdu, have highlighted the absence of a correlation between housing prices and the equity of park spaces (Cao et al., 2023).

Three potential reasons might account for the findings. First, variations in spatial patterns and geographic locations across different cities can impact economic attributes, thereby influencing the relationship between these attributes and the equity of parkland. The study area was the Central Area of Zhengzhou, which was characterized by relatively high and concentrated house prices. As illustrated in Fig. 15, house prices predominantly

cluster around 10,000 yuan. Second, previous studies typically considered the entire urban area, leading to significant disparities in housing prices between central and peripheral city regions. This disparity likely amplified the perceived impact of house prices on equity in the analysis. Third, both walking and cycling equity in the study area, when calculated using a 15-min threshold, showed inferior results. As depicted in Fig. 15, the values for walking and cycling equity were mostly concentrated between 0 and 1. The walking equity values were particularly close to zero, indicating numerous service deserts. Similarly, cycling equity values were low, averaging around 0.4. The overall inferior level of equity may diminish the influence of economic levels on equity.

Geographical factor. After analysis of calculation results, it was evident that the geographic spatial distribution and construction time of urban areas have a significant effect on the equity of parkland. Based on the Zone Entropy results, there were 9 streets with equity levels higher than the overall level, accounting for 11.25%, and 71 streets with equity levels lower than the overall level, accounting for 88.75%. There were several streets whose values were significantly higher than the average, including Songshan Street, Xincheng Street, Guxing Town Street, and Longyuan Street.

In Fig. 13, it can be seen that the streets with a higher Zone Entropy than the overall level were located at the perimeter of the study area. As shown in Figs. 2 and 3, there were a number of parks built for the purpose of ecological preservation on the verge of the study area while the population was relatively low. These parks made the Zone Entropy appear much higher than average. As a result, geographic distribution had a significant impact on the equity of park spaces in the study area.

Construction timing and intensity were also critical factors. As shown in Fig. 3, the population density and development intensity were high in the central part of the study area. In addition, there was a lack of control over the size of the site and the intensity of development during the initial stages of development and construction. This has led to continuous development and construction by developers in order to capture profits in the long-term urban development process. The change in urban land layout reflected competition between different interest groups. After a long period of evolution, some public spaces, such as parklands, became residential areas, indirectly causing the population density and development intensity of the center part of the study area to be much higher than that of the periphery.

On the other hand, at the periphery of the study area, the rationalization of the park layout was taken into account at the early stage of planning and construction. This was partly due to the relatively new construction date and updated planning concepts. From the phenomenal level, it appears that a significant amount of ecological land has been preserved in the periphery part and belongs to parkland nowadays. As compared to the core circle, the attractiveness of the metropolis has weakened significantly in the periphery, and the distribution of the population is generally dispersed. As a result, the periphery of the study area had more park spaces and a smaller population than the center, which made the calculations more equitable.

For example, Zhengdong New District, as a newly developed area, had higher housing prices, a smaller population, and a lower population density than other areas. The population density of the old urban areas, such as Erqi District and Guancheng Huiyuan District, was much higher than that of Zhengdong New District. Erqi District and Guancheng District were built earlier and had fewer parks. On the other hand, the planning and

construction of Zhengdong New District started after 2000. The number of parks was much higher than that in these two districts.

The above analysis explained that there was no obvious correlation between the residents' income situation and equity level. Rather, it was the geographic location and intensity of development, the degree of park construction, and the amounts of parks that were determinants of the equity of parkland.

Optimization strategies. According to the results, it is imperative that parks be designed in a child-friendly and elder-friendly manner. For the group aged 0–14 and aged over 65, whose mobility remains unchanged, there should be a further tilt in parkland resources. In addition to increasing the number of parks, the services and quality should be further increased. To improve the effectiveness of services as well as to improve the quality and humanity of old parks, it is critical that they are renovated rapidly.

For a balanced distribution of parks between new and old urban areas, it is necessary to take into account local conditions and residents' needs while preserving the original urban planning and construction. In particular, urban road edges and corners can be utilized to create pocket parks. Add more public spaces with flexible layouts and diverse forms to increase the number of urban parks. Through the development of corridors, small-sized playgrounds and community parks will be connected to increase service coverage and enhance the sense of well-being of residents.

During urban construction, the expansion of construction land should be strictly controlled so that urban green space can be created in a diversified manner. It is important for government departments to gradually relocate industrial and storage land from the old urban areas of Zhengzhou. The vacated land should be prioritized for the construction of a green space system, and all kinds of green space should be reserved and controlled without encroachment. As part of the land use planning process, consideration should be given to converting certain areas into parks and green spaces. Priority will be given to the construction of parkland, taking into account the existing use of the area, the surrounding transportation situation, population density, and other factors. There were some old districts and low utility sites in the study area that could be replaced or repurposed. The optimized space will be used as community parks, playgrounds, and other green infrastructure to meet the needs of residents.

Public transportation and road networks have a significant impact on the accessibility of parks and green spaces (Handy et al., 1997; Grengs, 2010). As a result of their transportation choices, residents of different socioeconomic backgrounds may experience different levels of access to parkland. In urban centers, public transportation and road networks are more developed compared to other regions. Low-income households depend more on public transportation because most of them may not have cars like the rich group. Increasing the density of the road network can improve accessibility to help them walk more easily to parks, which will lead to parkland equity increase. For residents to travel more efficiently, a mature transportation network system needs to be established in a timely manner during urban construction. The service scope of parks needs to be improved in order to enhance the utilization rate of urban parkland. Government departments must, therefore, improve city road network construction in old districts, increase public transportation use, increase access routes and stops, reduce the time cost of residents' travel, and make parks and green spaces more accessible.

Managers must establish a feedback mechanism for residents to ensure that their wishes can be fully expressed. To realize the equity of parkland, managers must consider not only the equity of the parkland allocation process but also the equity of residents' participation. Especially for the vulnerable groups, their right to enjoy parkland should be guaranteed. Equity includes the degree of participation of users in the green space. Therefore, in the planning and construction of parkland, it is imperative to facilitate the participation of everyone in a fair manner, so that equity will become a social responsibility of urban planners.

Research outlook. This study constructed the process equity evaluation model based on spatial accessibility and the outcome equity evaluation model based on demographic characteristics, incorporating two research dimensions to evaluate the parkland in the Central Area of Zhengzhou. However, further research is still needed. Because of the limitation on research scope, this paper is unable to cover residents' evaluation of parkland. Therefore, this study ignored the specific uses of the parks based on the behavioral characteristics of the users. There is a need to invest residents' willingness to parkland and their preferences, which can be used as a guide to carry out further optimization in the future.

This study utilized data from the Sixth National Census, hence exhibiting a time lag in analysis. Compared to the data from the Sixth National Census, the Seventh National Census data shows significant improvement. Consequently, in reality, the population in the study area should be higher than the number calculated in this research. Both park and road network data were collected in 2023, reflecting the current situation of the study area. While the data of parks and road networks used for the calculation were recent, the population data was relatively outdated, potentially leading to an overestimation of the equity in the distribution of parks.

However, Zhengzhou city has not released street-level data from the Seventh National Census. Therefore, a more detailed analysis at a finer granularity is not feasible, nor is it possible to focus on specific social attributes. Future research could combine data from the Sixth and Seventh National Censuses to study the dynamic equity of parkland, along with policy analysis, to evaluate the dynamic changes in the equity.

Another limitation of the study is the exclusion of a more diverse range of social factors. Due to data constraints, factors such as the educational level and unemployment status of users' were not considered in this study. Future studies should adopt a multidisciplinary approach and integrate multi-source heterogeneous data to comprehensively consider the social factors and actual needs of users.

Data availability

Population data was obtained from Liu S, Qi W (2000) 2010 Chinese urban spatial dataset, 2018. Institute of Geographic Sciences and Resources, Chinese Academy of Sciences, Beijing <https://doi.org/10.12237/casearth.5c19a5670600cf2a3c557afa>. Accessed 24 May 2023. Available at: <https://data.casearth.cn/sdo/detail/5c19a5670600cf2a3c557afa>. Road network data and parkland space data were obtained from an Open street map. 2014–2021 OSM China POI Data 2022. <https://doi.org/10.11878/db.202205.006580>. Accessed 15 April 2023. Available at: <https://chinageoss.cn/datasharing/datasetDetails/62725f064984d37e565d798c>. 3. Authors are not authorized to provide residential area data.

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Notes

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Author contributions

Conceptualization, YG and YC; methodology, YG; software, YG; validation, YG and YC; formal analysis, YC; investigation, YG; resources, YL; data curation, YG and YF; writing—original draft preparation, YG, YL, and RW; writing—review and editing, YG; visualization, YC and YG; supervision, YG; project administration, YG and YF. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

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